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U.S. PATENT DOCUMENTS

Search Selected Search ALL Clear

	PAT-NO	ISSUE-DATE	PATENTEE-NAME	US-CL
☐	3882717	May 1975	McCauley	73/600
☐	4275589	June 1987	Dugger et al.	73/146

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ABSTRACT:

A method and apparatus for non-destructive ultrasonic testing of tires is disclosed wherein an ultrasonic transmitter is positioned outside of the tire and applies pulses of ultrasound to the tire at a plurality of locations around the tire's circumference for transmission through the tire wall and receipt by an ultrasonic receiver located within the tire. The ultrasonic receiver generates signals in response to the received ultrasonic transmissions and a computer processes these signals to generate characterizing data from which defects in the tire may be determined. Signals representative of the defects are then processed to generate a graphic display illustrating the location of the defects with the tire.

22 Claims, 17 Drawing figures

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Brief Summary Text (6):
U.S. Pat. Nos. 4,266,428, 4,285,235 and 4,275,589 disclose an apparatus and method for nondestructive testing of tires with ultrasound. More specifically, these patents teach the use of pair of ultrasonic transmitters having a beam width of 90.degree. that are positioned within a tire that preferably has been buffed, i.e. had the tread pattern ground off in preparation for retreading. The apparatus retracts the transmitters into a central hub during installation and removal of the tire and extends them into the tire during testing. These transmitters produce ultrasound of a moderately high frequency, e.g. greater than approximately 40 KHz and, preferably, 75 KHz. The ultrasound rom these transmitters is applied to wall of a tire inflated to approximately 15-18 pounds per square inch ("PSI"). Numerous ultrasonic receivers are arranged about the tire's outer surface to receive ultrasound from one or the other of the transmitters. In addition to receiving ultrasonic signals from the transmitters within the tire, these receivers can also detect air leaking through the pressurized tire.

Brief Summary Text (7):
In testing a tire with ultrasound, the apparatus disclosed in these patents operate in a pulse burst transmission mode in which only a few periods (e.g. 30-100) of the acoustic waveform are applied to the tire. According to these patents, the use of pulse burst transmission allegedly reduces standing waves in the tire or unwanted reverberation effects. The two transmitters, located inside the inflated, revolving tire, are energized separately allegedly to prevent distortion of readings from peculiar wave cancellation, standing wave patterns or similar wave effects.

Brief Summary Text (8):
These patents also disclose that the electrical signal produced by the receivers passes through a gated receiver circuit so that only those signals within the initial portion (e.g. the first 10 cycles) of each pulse burst are used in testing the tire. According to these patents, using only the initial portion of each pulse burst reduces alteration of the envelope of the received acoustic signals by internal reverberation, standing wave, wave cancellation or other wave effects.

Brief Summary Text (9):
The gated receiver circuit included in each signal processing channel for each receiver includes an Automatic Gain Control ("AGC") amplifier. These patents disclose that the AGC amplifier is required to compensate both for differing wall thicknesses within a single tire, and for differing thicknesses between tires. The gated receiver also includes a rectifying circuit and an integrating circuit to average the signal over several cycles during the beginning of each pulse burst. To further improve the signal-to-noise ratio, the apparatus may also include a non-linear Analog-to-Digital Converter ("ADC") that digitizes the output signal from the integrating circuit.

Brief Summary Text (11):

Despite the use of complex signal processing circuits and techniques in the apparatus disclosed in these patents, commercially available versions exhibit operational difficulties which limit their use. For example, the apparatus is extremely sensitive to noise from surrounding equipment. Accordingly, it is often necessary to isolate the apparatus in a special "quiet" room separated from other tire processing equipment. While the apparatus disclosed in these patents provides a visual oscilloscopic display of the testing results, reliably rejecting defective tires while not rejecting good ones requires observation and analysis of the display by an experienced and highly skilled operator. Also, this apparatus cannot reliably test treaded tires, i.e. tires that still retain a tread pattern and that are thicker than a buffed tire. Because these prior art products require buffing prior to ultrasonic testing, the time and cost of buffing a tire must first be expended before it may be discovered that the tire is defective and cannot be retread.

Brief Summary Text (21):
Briefly, the present invention includes a method for nondestructive testing of tires that employs pulses of ultrasound transmitted from an ultrasonic transmitter located on one side of a wall of a tire to an ultrasonic receiver located on the opposite side of the tire's wall. In this method of ultrasonic tire testing, the transmission of ultrasound through the tire's wall is characterized at a plurality of locations along the circumference of the tire. This characterization is obtained by successively applying a series of pulses of ultrasound to the tire's wall with the ultrasonic transmitter and sensing ultrasonic emanations from the wall with an ultrasonic receiver. Each characterization of the transmission of ultrasound through the wall of the tire is then accumulated for a plurality of locations distributed circumferentially about the tire. The method of the present invention then identifies a repetitive pattern present in the accumulated characterizations of ultrasound transmission through the wall of the tire. This repetitive pattern is then used in identifying defective areas on the tire when searching the accumulated characterizations of ultrasonic transmission.

Brief Summary Text (23):
A nondestructive tire testing apparatus in accordance with the present invention includes an encoder that produces an electronic signal indicative of tire rotation. The apparatus also includes electronic circuits that cause pulses of ultrasound to be produced periodically by exciting the ultrasonic transmitters at locations distributed around the circumference of the tire. A signal processing circuit included in the apparatus receives an electronic signal from the ultrasonic receiver and measures values of that signal for each pulse of ultrasound. The signal processing circuit then stores those measured values for subsequent analysis. The apparatus includes a computer that retrieves the values stored by the signal processing circuit and analyzes the stored values to determine the characteristics of the transmission of ultrasound through the tire's wall from the measured values. Further, the computer identifies defective locations on a tire from the characteristics of the ultrasound transmitted through the tire's wall.

Drawing Description Text (11):
FIG. 10 is a flow chart depicting steps performed to find a pattern in the pulsed ultrasound data during the data analysis illustrated in FIG. 7B;

Drawing Description Text (12):
FIG. 11 is a diagram depicting the selection of data values for the determination of pattern length as illustrated in FIG. 10;

Detailed Description Text (34):
The encoder counter 192 also receives and counts pulses received from the shaft angle encoder 64 over an encoder signal line 193 while the tire 34 rotates. When the number of pulses from the shaft angle encoder 64 equal the number with which the encoder counter 192 is preset by the computer 122, a flip-flop included in the

encoder counter 192 is set. Setting of the flip-flop included in the encoder counter 192 causes the digital interface card 168 to transmit a signal to an interrupt input of the DIO board 162 via an encoder interrupt signal line 194 included in the multi signal bus 166. Concurrently with the transmission of the interrupt signal to the DIO board 162, the encoder counter 192 is immediately again preset with the count then present on the encoder count bus 188. Thus, it immediately resumes counting pulses from the shaft angle encoder 64 in preparation for the next ultrasound scan across the width of the tire 34.

Detailed Description Text (38):
When data sampling begins, the AI board 164 commences transmitting a signal to the digital interface card 168 via a data sampling control signal line 212 included in the multi-signal bus 166. Commencement of the signal on the data sampling control signal line 212 causes a multi-vibrator 214 included in the digital interface card 168 to transmit a single, 100 microsecond long ultrasound transmit interval pulse. This output pulse from the multi-vibrator 214 is transmitted via a pulse interval signal line 216 and an inverter 218, included in the transmitter selector circuit 182, to the transmitter selector multiplexer 206. Occurrence of the 100 microsecond long pulse on the pulse interval signal line 216 causes the transmitter selector multiplexer 206 to transmit a corresponding 100microsecond long pulse on that one of its output signal lines 208 specified by the signals present on the transmitter-receiver selector bus 204.

Detailed Description Text (39):
The 100 microsecond long pulse present on the selected output signal line 208 of the transmitter selector multiplexer 206 is applied through an inverter 222 and a resistor 224 to the base of a transistor 226. The emitter of the transistor 226 is connected to circuit ground while its collector is connected to the junction of a resistor 332 with a capacitor 334. When the pulse is absent from the output signal line 208 of the transmitter selector multiplexer 206, the transistor 226 is turned off and the junction of the resistor 332 and the capacitor 334 charges to a +340 volt potential applied to the other terminal of the resistor 332. When the pulse occurs on the selected output signal line 208, the transistor 226 turns on thereby grounding the junction of the capacitor 334 with the resistor 332 and discharging the capacitor 334. Discharging the capacitor 334 applies a 340 volt negative spike across one pair of 16 pairs of leads 236 included in a transmitter drive signal bus 238 that connects the transmitter selector circuit 182 to the ultrasonic transmitters 94 in the transmitter array 92. Application of the -340 volt negative spike energizes the ultrasonic transmitter 94, to which to the leads 236 connect, to emit a pulse of ultrasound having a frequency of approximately 40 KHz.

Detailed Description Text (40):
After the AI board 164 collects all 1024 data samples for this pulse of ultrasound, it removes the signal present on the data sampling control signal line 212. Ending of the signal present on the data sampling control signal line 212 causes the count present in the transmitter and receiver counter 202 to increment by one. Incrementing the count present in the transmitter and receiver counter 202 changes the signals present on the transmitter-receiver selector bus 204. Changing the signals present on the transmitter-receiver selector bus 204 causes the transmitter selector multiplexer 206 to select a different ultrasonic transmitter 94 to be energized when the AI board 164 again begins collecting data and thereupon again commences transmitting a signal to the digital interface card 168 via a data sampling control signal line 212.

Detailed Description Text (42):
After the AI board 164 has completed collecting 1024 data samples for all 16 pulses of ultrasound, the DIO board 162 sends a signal to the encoder counter 192 and to the transmitter and receiver counter 202 over a clear the encoder interrupt signal line 240 included in the multi-signal bus 166. The signal on the clear the encoder interrupt signal line 240 resets the flip-flop included in the encoder counter 192

to remove the interrupt signal from the input of the DIO board 162 thereby enabling the encoder counter 192 to send the next interrupt to the DIO board 162. The signal on the clear the encoder interrupt signal line 240 also resets the transmitter and receiver counter 202 thereby insuring that the transmission of pulses of ultrasound always begins with the same ultrasonic transmitter 94.

Detailed Description Text (48):
Signals for selecting which of the 16 transmitter output signals supplied to the input amplifying-multiplexers 276 will be transmitted from the receiver multiplexing circuit 184 are supplied, via the transmitter-receiver selector bus 204, from the transmitter and receiver counter 202, included in the digital interface card 168, to the opto-isolator 282 included in the receiver multiplexing circuit 184. Consequently, the output signal from the same receiver 104 is transmitted from the receiver multiplexing circuit 184 throughout the entire interval during which the AI board 164 maintains the signal on the data sampling control signal line 212 and collects all 1024 data samples for each pulse of ultrasound. The change of signals that occurs on the transmitter-receiver selector bus 204 when the AI board 164 completes its data collection causes the receiver multiplexing circuit 184 to immediately select the output signal from a different ultrasonic receiver 104 for transmission from the output amplifying-multiplexer 302. Accordingly, proper arrangement of the ultrasonic transmitters 94 and receivers 104 results in the coordinated operation of the transmitter selector circuit 182 to excite one ultrasonic transmitter 94 and produce a pulse of ultrasound while the receiver multiplexing circuit 184 simultaneously transmits the output signal from the ultrasonic receiver 104 with which that transmitter 94 is paired.

Detailed Description Text (52):
The output signal from the bandpass filter circuit 342 is applied to the input of a logarithmic amplifier circuit 346 that includes an amplifier 348. The logarithmic amplifier circuit 346 permits the tire apparatus 20 to operate with output signals from the ultrasonic receivers 104 which differ widely in amplitudes. Accordingly, the logarithmic amplifier compensates for variations among the performances of the ultrasonic transmitters 94 and the ultrasonic receivers 104. In addition, the logarithmic amplifier circuit 346 allows the apparatus 20 to test individual tires 34 that have walls 72 which differ greatly in thicknesses including thickness variations due to tread pattern present on the tire 34, and to test various types of tires 34 having widely differing thicknesses.

Detailed Description Text (63):
FIG. 8 illustrates the timing for single pulse of ultrasound applied to the tire 34 during processing step 416 by the combination of the digital interface card 168, the transmitter selector circuit 182 and the ultrasonic transmitters 94. After multi-vibrator 214 transmits its 100 microsecond long pulse on the pulse interval signal line 216 in response to the signal from the AI Board 164 on the data sampling control signal line 212, there is a delay required for transmission of ultrasound from the transmitter 94 through the wall 72 of the tire 34 to the receiver 104 before the signal on the receiver multiplexer output signal line 306 responds to the ultrasound pulse. The signal and its envelope shown for the receiver multiplexer output signal line 306 depicted in FIG. 8 is only illustrative. The shape of the signal present on the line 306 varies greatly among the 16 receivers 94 during a single scan across the width of the tire 34 and varies for a single receiver 104 throughout the circumference of the tire 34. Approximately every 1.6 milliseconds for a comparatively long time after the pulse of ultrasound is generated, the AI board 164 repetitively converts the signal from the ultrasonic receiver 104 present on the analog input signal line 356 into a digital number storing that number into a memory located on the AI board 164. Since the AI board 164 collects 1024 samples of the signal from the ultrasonic receiver 104 at a sampling frequency of 625 KHz, more than 10 samples of the ultrasound are collected during each period of the 40 KHz signal produced by the ultrasonic

transmitter 94, and data for approximately 65 periods of that 40 KHz signal are collected.

Detailed Description Text (70):
Because the effect of tread pattern on the signal from one receiver 104 may differ greatly from immediately adjacent receivers 104 on either side, the signals from each of the receivers 104 are analyzed independently one after another. The data for each receiver 104 is processed as an elongated continuous strip from the data for the first scan along the circumference of the tire 34 to the data for the last scan. Furthermore, the data for each tire 34 is processed the same whether or not it actually has a tread pattern, i.e., whether or not the tire 34 has been buffed. It has been discovered that the ultrasound transmission data for buffed tires 34 frequently exhibits a pattern apparently due to the internal structure of the tire 34.

Detailed Description Text (71):
In processing step 432, the computer program finds the length of the pattern present in the data in a single column of the array 426. Having found the length of the pattern, the program then increases the resolution of the data in processing step 434 by computing a value between each pair of data in the array 426 and storing both the actual data and the interpolated values intermixed into an vector 446 illustrated in FIG. 9. Thus, the vector 446 contains one fewer data value than twice the number of scans. The computer program uses a standard cubic spline routine to compute the interpolated values in processing step 434.

Detailed Description Text (72):
In processing step 436, the computer program computes the length of the pattern in the increased resolution data in the vector 446. Having found the pattern length in the increased resolution data, the computer program then identifies possibly defective locations on the tire 34 by searching the increased resolution data in the vector 446 and stores data that indicates the possibility of a defect in a column of an array 448. Having stored data that indicates the possibility of a defect into a column of the array 448, in processing step 440 the computer program then compresses the entries in the column of the array 448 for the present receiver 104 discarding the values at those locations where interpolated values were computed in evaluating the vector 446.

Detailed Description Text (73):
Finding the Pattern Length

Detailed Description Text (74):
As depicted in the flow chart in FIG. 10, finding a pattern in the data for a receiver 104, processing steps 432 and 436 in FIG. 7B, begins with an initiation step 452. In initiation step 452, a minimum test pattern length, such as the value 5, is assigned to be used for initially comparing values of the data from the receiver 104. If the present test pattern length does not exceed a maximum value, a decision step 454 causes the data for the receiver 104 to be processed using the present test pattern length.

Detailed Description Text (75):
In a processing step 456, the computer program determines the magnitude of the difference between successive values in the data that are separated by the current test pattern length. FIG. 11 graphically illustrates the selection of data values used in determining the magnitude of their difference when the test pattern length is 5. As illustrated by each U-shaped lines 458 in FIG. 11, the magnitude of the difference between data values 5 locations apart is determined. Thus, for example, the magnitude of the difference between data values 1 and 6, data values 2 and 7, data values 3 and 8, etc. are determined. The magnitude of the difference between the data values is determined by computing the absolute value of the difference between the data values.

Detailed Description Text (76):
Having determined the magnitude of the differences between the data values for the present pattern length, those magnitudes are then compared in a processing step 462 to determine if they exceed a threshold value. The threshold value with which each magnitude is compared is the sum of a constant value, that represents the overall system noise for the apparatus 20, plus 2% of the value of the first data of the pair for which the magnitude was determined. Thus, the threshold with which each magnitude is compared depends upon the value of the data for which the magnitude was computed. A processing step 464 counts the total number of magnitudes that are computed in processing step 456.

Detailed Description Text (77):
In a processing step 466, the program executed by the computer 122 computes a ratio of the two counts accumulated respectively in processing steps 462 and 464. This ratio must always be 1.0 or less and can never be less than 0.0. The ratio computed in processing step 466 is then compared in a decision step 468 with the minimum value for that same ratio determined for preceding values of the test pattern length. If the ratio for the present test pattern length is less than the ratio for all preceding test pattern lengths, then the present ratio and the present test pattern length are saved in a processing step 472.

Detailed Description Text (78):
If a pattern exists in the data for a receiver 104, then the difference between data values separated by the length of that pattern will, on the average, tend to be small. Consequently, if a test pattern length equals the actual pattern length for data from a receiver 104, there will be few differences between pairs of that data separated by the test pattern length whose magnitude exceeds some threshold value. By counting the number of differences whose magnitude exceeds a threshold value and computing the ratio of that count to the total number of differences, the ratio thus obtained measures how poorly a test pattern length matches the pattern in the data from the receiver 104. Consequently, a high ratio indicates that the test pattern length does not match the pattern length in the data while a lower ratio for a test pattern length indicates a better match for the data's pattern length.

Detailed Description Text (79):
Whether or not the ratio and the test pattern length are saved in processing step 472, the computer program then increases the test pattern length by one in a processing step 474 and returns to processing step 454. In processing step 454, the computer again tests the new, longer test pattern length to determine whether or not it exceeds the maximum allowed test pattern length. If the test pattern length exceeds the maximum allowed, the computer program then executes a terminator step 476 and returns the last value of the pattern length stored in processing step 472 to the calling procedure as the pattern length for the data being processed for the current receiver 104.

Detailed Description Text (80):
The process of finding the pattern length remains the same whether a pattern is being found directly in the data from the receiver 104 as stored as a column in the array 426 or it is being found in the increased resolution data stored in the vector 446. The only difference Between finding patterns for the data stored in the array 426 and the vector 446 are the minimum and maximum values of the test pattern length. Because an approximate pattern length is already known for the increased resolution data stored in the vector 446, ratios for only a few test pattern lengths must be compared to obtain the pattern length for the increased resolution data.

Detailed Description Text (82):
FIG. 12A and 12B depict the steps that are performed in identifying possibly

defective locations on the tire 34 as shown in processing step 438 in FIG. 7B. Finding possibly defective locations on the tire 34 begins with a terminator step 482. The terminator step 482 requires that the present pattern length be used in processing the increased resolution data to identify the location of possible defects. Identifying the location of possible defects begins with the first location in the vector 446. A decision step 484 immediately following the terminator step 482 requires that all data values in the increased resolution data stored in the vector 446 must be processed before returning to the calling procedure at a terminator step 486. Thus all locations in the vector 446 beginning with the first and ending with the last are processed through decision step 484.

Detailed Description Text (83):
If all of the data in the vector 446 has not been processed, then decision step 484 causes a decision step 488 to be executed. Decision step 488 determines whether the present location is within one pattern length of either end of the vector 446. If the present value is not within one pattern length of either end of the vector 446, then a decision step 492 is executed. The decision step 492 compares the value in the present location in the vector 446 with both of those values one pattern length on either side of the present location. Thus, if the pattern length in the increased resolution data was found to be 20 and the present location was 40, the value at location 40 would be compared both with the value at location 20 and with the value at location 60.

Detailed Description Text (84):
Analogous to the process of finding a pattern length in the data, in decision step 492 the computer program computes the magnitude of both the differences between the value of the data at the present location in vector 446 and the values one pattern length on either side of the present location. Having computed the magnitude of these two differences by taking their respective absolute values, the program then compares those magnitudes with a threshold value. In a manner analogous to the finding of a pattern length, the threshold value with which each magnitude is compared is the sum of a constant value, the assigned defect level for the testing apparatus 20, plus 2% of the value of the data at the present location. Thus again, the threshold with which each magnitude is compared depends upon the value of the data for which the magnitude was computed. If either of these two magnitudes is less than the threshold value, a value is assigned in a processing step 494 for storage in the array 448 which marks this location in the vector 446 as not having a defect, i.e. a zero value is assigned for storage into the array 448.

Detailed Description Text (85):
FIG. 13A graphically depicts the conditions under which decision step 492 will cause processing step 494 to be executed. In FIG. 13A a dot 496 represents the data at the present location. A horizontal line 498 indicates the value of the data and a vertical line 502 extending upward above the number 0 indicates the data's location within the vector 446. Horizontal dashed lines 504A and 504B represent the respective threshold levels above and below the value depicted by the line 498 against which the magnitudes will be compared. If a data value illustrated by a dot 506A one pattern length "P" below (-) the current data location lies along a vertical double headed arrow 508A extending between the upper threshold 504A and the lower threshold 504B or if a data value illustrated by a dot 506B one pattern length "P" above (+) current data location lies along a vertical double headed arrow 506B also extending between the upper threshold 504A and the lower threshold 504B, then decision step 492 causes processing step 494 to be executed.

Detailed Description Text (86):
Thus, for locations more than one pattern length from the ends of the vector 446, if the data values one pattern length on either side of the present location are within plus or minus the threshold value, the present location is marked as not having a defect. Thus, the present location will be marked as not having a defect if the slope to either of the data values one pattern length on either side of the

present location is sufficiently flat.

Detailed Description Text (87):
Referring again to FIG. 12A, if the respective slopes to both data values one pattern length on either side of the present location are insufficiently flat, decision step 492 causes another decision step 512 to be executed. Thus, decision step 512 is executed only if decision step 492 determines that the two magnitudes are both greater than the threshold value in decision step 492.

Detailed Description Text (88):
FIG. 13B depicts the condition under which decision step 512 is executed. Items identified by reference numbers in FIG. 13B having a "'" designation are the same as those identified by that same reference number in FIG. 13A. For decision step 512 to be executed, the data value one pattern length "P" below (-) the current data location must lie either along a vertical arrow 514AU pointing upward above the upper threshold 504A' or must lie along a vertical arrow 514AL pointing downward below the lower threshold 504B', and the data value one pattern length "P" above (+) current data location must also lie either along a vertical arrow 514BU pointing upward above the upper threshold 504A' or along a vertical arrow 514BL pointing downward below the lower threshold 504B'. Consequently, decision step 512 can be executed only if the present location is on a slope in the data values extending from somewhere on the upper arrow 514AU down through the dot 496' to somewhere on the lower arrow 514BL, on a slope in the data values extending from the lower arrow 514AL upward through the dot 496' to somewhere on the upper arrow 514BU, at the nadir of a "V" in the data values with the other two data values respectively lying somewhere on the upper arrows 514AU and 514BU, or at the peak of an inverted "V" with the other two data values respectively lying somewhere on the lower arrows 514AL and 514BL.

Detailed Description Text (89):
Referring again to FIG. 12A, decision step 512 determines whether or not the data value at the present location is a minimum or a maximum by determining whether the magnitude of the difference between the two data values one pattern length below (-) and one pattern length above (+) the present location exceeds the same threshold as that used in decision step 492. If the magnitude of this difference does not exceed that threshold, then a processing step 516 is executed. Consequently processing step 516 is executed only if the present location is a minimum or a maximum in the data values with respect to those one pattern length below (-) and one pattern length above (+) the present location and only if the slope between the data values one pattern length below (-) and one pattern length above (+) is sufficiently flat. If processing step 516 is executed, then the following value is computed for assignment to the current location in the array 448. ##EQU1##

Detailed Description Text (90):
If the present location is not a minimum or a maximum in the data values with respect to those one pattern length below (-) and one pattern length above (+) the present location, or if it is a minimum or a maximum but there is an excessive slope between the data values one pattern length below (-) and one pattern length above (+), then decision step 512 causes a decision step 518 to be executed.

Detailed Description Text (91):
Decision step 518 causes the magnitude of the difference between successive pairs of data values in the vector 446 at locations that are separated by one pattern length and that are offset by multiple pattern lengths with respect to the present location to be compared successively one after another with a threshold value. For example, for the prior example in which the pattern length in the increased resolution data was found to be 20 and the present location was 40, depending upon the actual data values decision step 518 could cause the magnitude of the difference to be compared with a threshold value for the following data locations.

Detailed Description Text (92):
So long as the magnitude of the difference at each of these successive locations is greater than the corresponding threshold, decision step 518 continues comparing the magnitudes of the differences with the corresponding threshold value for locations further and further from the present location. This process by decision step 518 halts only upon finding a difference in the data values whose magnitude is less than the threshold value, or upon reaching the limits of data in the vector 466. Furthermore, for present locations such as those described thus far that are more than one pattern length from both ends of the vector 446, the decision step 581 searches in the preceding manner both below (-) and above (+) the present location.

Detailed Description Text (95):
As illustrated in FIG. 12A and 12B, for present locations such as those described thus far that are more than one pattern length from the ends of the vector 446, after executing processing steps 494, 516 or 522 the computer program executes a processing step 526. In processing step 526, the value assigned in processing step 494 or either of the weighted differences computed in processing steps 516 or 522 are stored into the present location in the array 448. After storing the data value into the array 448 in processing step 526, the computer program executes a processing step 528 which increments to the location of the next data value in the increased resolution data present in the vector 446.

Detailed Description Text (96):
After incrementing to the location of the next data value, the computer program again executes decision step 484 to determine if all the data values in the vector 446 have been processed. As discussed previously in connection with decision step 484, if all data values have not been processed then decision step 488 is executed. If the present location is within one pattern length from either end of the vector 446, then decision step 488 causes a decision step 532 to be executed rather than decision step 492. Decision step 532 determines whether the present location is within one pattern length of the first end of the vector 446. If the present location is within one pattern length of the first end of the vector 446, then the present location is within the first pattern in the data and a decision step 534 is executed. If the present location is not within one pattern length of the first end of the vector 446, then it must be within one pattern length of the final pattern in the vector 446 and a decision step 536 is executed.

Detailed Description Text (97):
Decision step 534 is analogous to decision step 492 except that only the magnitude of the difference with the data value one pattern length above (+) the current location is compared with the threshold value. Analogously, decision step 536 is similar to decision step 492 except that the magnitude of the difference with the data value one pattern length below (-) the current location is compared with the threshold value. The threshold value for decision steps 534 and 536 are determined in precisely the same manner as the threshold value for the decision step 492. As with decision step 492, if decision steps 534 or 536 find that the respective slopes to the respective data values one pattern length above (+) or below (-) the present location are sufficiently flat, a processing step 494' identical to processing step 494 is executed.

Detailed Description Text (98):
Conversely, if decision steps 534 or 536 find that the respective slopes to the respective data values one pattern length above (+) or below (-) the present location are excessive, decision steps 542 or 544 are executed. Decision steps 542 and 544 are analogous to decision step 518 except that rather than searching in both below (-) and above (+) the present location, decision step 542 searches only pattern lengths above (+) the present location and decision step 544 searches only pattern lengths below (-) the present location. If decision step 542 finds a flat spot above (+) the present location, then a processing step 522' analogous to

processing step 522 is executed. Correspondingly, if decision step 544 finds a flat spot below (-) the present location, then a processing step 522" also analogous to processing step 522 is executed. If either decision steps 542 or 544 fails to find a flat spot, then analogous to decision step 518 processing step 494' is executed.

Detailed Description Text (99):
In the preceding manner, all values for the increased resolution data for the current receiver 104 that are stored in the vector 446 are processed using the pattern length found in processing step 436.

CLAIMS:

1. A non-destructive method for testing a tire employing pulses of ultrasound transmitted from an ultrasonic transmitter located on one side of a tire wall to an ultrasonic receiver located on the opposite side of the tire wall, the tire wall having an outer surface and an inner surface which when sealed may be pressurized, said method comprising the steps of:

generating characterizing data from the transmission of ultrasound through the tire wall at a plurality of locations around the circumference of the tire by successively applying a series of pulses of ultrasound to the tire wall with the ultrasonic transmitter, sensing the ultrasound emanating from the tire wall with the ultrasonic receiver, and processing a signal produced by the ultrasonic receiver in response to said ultrasonic emanations;

accumulating said characterizing data for said plurality of locations distributed circumferentially around the tire;

determining a repetitive pattern present in the accumulated data; and

identifying defective areas in the tire using the repetitive pattern in searching the accumulated data for such defective areas.

11. The method of claim 1 wherein the repetitive pattern present in the accumulated data is determined by finding a length for such pattern.

12. The method of claim 11 wherein the length of the repetitive pattern present in the accumulated data is found by:

determining the magnitude of the difference between pairs of characterizing data for a plurality of pairs of locations which are all separated by a first specified distance;

counting the number of such differences whose magnitude exceeds a threshold value;

counting the total number of such differences;

determining a ratio of the number of differences whose magnitude exceeds the threshold value to the total number of differences;

determining if the ratio thus determined is less than other ratios obtained for other specified distances different from the first specified distance; and

assigning as the pattern length the specified distance that has the lowest ratio of the number of differences whose magnitude exceeds the threshold value to the total number of differences.

13. The method of claim 1 wherein the repetitive pattern is used in searching for defective areas by selecting for comparison pairs of the accumulated data that have the same location with respect to the repetitive pattern.

18. A nondestructive tire testing apparatus, comprising:

encoder means for producing an electronic signal indicative of rotation of a tire;

a plurality of electronic transmitters for producing ultrasound upon excitation by an electronic signal;

transmitter exciting means responsive to the electronic signal from said encoder means for periodically exciting said ultrasonic transmitters to produce pulses of ultrasound at various locations around a circumference of a tire; said transmitter exciting means including transmitter selection means for selecting said ultrasonic transmitters for excitation one after another thereby causing said ultrasonic transmitters to produce a series of ultrasound pulses, said series of ultrasound pulses being produced periodically in response to the electronic signal from said encoder means at various locations around a circumference of a tire;

a plurality of ultrasonic receivers equal to said plurality of ultrasonic trasmitters for receiving ultrasound and producing an electronic signal in response thereto, said transmitters and receivers being grouped into pairs, and said ultrasonic receivers being spaced from said ultrasonic transmitters to permit a single wall of a tire to pass there between;

signal processing means for receiving the electrical signal from said ultrasonic receivers, for measuring values of the received electronic signal which characterize the transmission of ultrasound through a wall of a tire, and for storing said measured values;

data processing means for retrieving the measured values stored by said signal processing means, for determining characteristics of the transmission of ultrasound through a wall of a tire from said measured values at a plurality of locations distributed circumferentially about a tire, and for identifying defective locations on a tire from the characteristics of the ultrasound transmitted through a wall of a tire; and

receiver signal multiplexing means, coupling the electronic signal from said ultrasonic receivers to said signal processing means and operating in synchronism with said transmitter selection means, for selectively coupling to said signal processing means the electronic signal from that ultrasonic receiver which is paired with the ultrasonic transmitter selected for excitation by said transmitter selection means.

19. A nondestructive tire testing apparatus, comprising:

encoder means for producing an electronic signal indicative of rotation of a tire;

a plurality of electronic transmitters for producing ultrasound upon excitation by an electronic signal;

transmitter exciting means responsive to the electronic signal from said encoder means for periodically exciting said ultrasonic transmitters to produce pulses of ultrasound at various locations around a circumference of a tire; said transmitter exciting means including transmitter selection means for selecting said ultrasonic transmitters for excitation one after another thereby causing said ultrasonic transmitters to produce a series of ultrasound pulses, said series of ultrasound pulses being produced periodically in response to the electronic signal from said encoder means at various locations around a circumference of a tire;

a plurality of ultrasonic receivers for receiving ultrasound and producing an electronic signal in response thereto, said ultrasonic receivers being arranged

into an array shaped to conform to a cross-section of an inner surface of a tire and spaced from said ultrasonic transmitters to permit a single wall of a tire to pass there between;

receiver positioning means for retracting said array of ultrasonic receivers out of a tire during tire removal or installation and for inserting said array of ultrasonic receivers into a tire toward the inner surface thereof during tire testing, said receiver positioning means rotating said array of ultrasonic receivers about an axis after said array is within a tire to dispose said ultrasonic receivers across such tire between sidewalls thereof;

signal processing means for receiving the electrical signal from said ultrasonic receivers, for measuring values of the received electronic signal which characterize the transmission of ultrasound through a wall of a tire, and for storing said measured values; and

data processing means for retrieving the measured values stored by said signal processing means, for determining characteristics of the transmission of ultrasound through a wall of a tire from said measured values at a plurality of locations distributed circumferentially about a tire, and for identifying defective locations on a tire from the characteristics of the ultrasound transmitted through a wall of a tire.

20. A nondestructive tire testing apparatus, comprising:

encoder means for producing an electronic signal indicative of rotation of a tire;

an ultrasonic transmitter for producing ultrasound upon excitation by an electronic signal;

transmitter exciting means responsive to the electronic signal from said encoder means for periodically exciting said ultrasonic transmitter to produce pulses of ultrasound at various locations around a circumference of a tire;

an ultrasonic receiver for receiving ultrasound and producing an electronic signal in response thereto, said ultrasonic receiver being spaced from said ultrasonic transmitter to permit a single wall of a tire to pass there between;

signal processing means for receiving the electrical signal from said ultrasonic receiver, for measuring values of the received electronic signal which characterize the transmission of ultrasound through a wall of a tire, and for storing said measured values;

data processing means for retrieving the measured values stored by said signal processing means, for determining characteristics of the transmission of ultrasound through a wall of a tire from said measured values at a plurality of locations distributed circumferentially about a tire, and for identifying defective locations on a tire from the characteristics of the ultrasound transmitted through a wall of a tire;

tire sensing means for contacting an outer surface of a tire to measure a diameter thereof; and

pulse location control means operative in conjunction with said transmitter exciting means to establish the locations around a circumference of a tire at which said ultrasonic transmitter will be excited.

21. A nondestructive tire testing apparatus comprising:

encoder means for producing an electronic signal indicative of rotation of a tire;

an ultrasonic transmitter for producing ultrasound upon excitation by an electronic signal;

transmitter exciting means responsive to the electronic signal from said encoder means for periodically exciting said ultrasonic transmitter to produce pulses of ultrasound at various locations around a circumference of a tire;

an ultrasonic receiver for receiving ultrasound and producing an electronic signal in response thereto, said ultrasonic receiver being spaced from said ultrasonic transmitter to permit a single wall of a tire to pass there between;

signal processing means for receiving the electrical signal from said ultrasonic receiver, for measuring values of the received electronic signal which characterize the transmission of ultrasound through a wall of a tire, and for storing said measured values;

data processing means for retrieving the measured values stored by said signal processing means, for determining characteristics of the transmission of ultrasound through a wall of a tire from said measured values at a plurality of locations distributed circumferentially about a tire, and for identifying defective locations on a tire from the characteristics of the ultrasound transmitted through a wall of a tire; and

tire mounting means adapted to seal a tire so it may be pressurized, said tire mounting means including a hub on each side of a tire together with rings which may be of various different outer diameters to adapt said tire mounting means for use with various different sizes of tires, one such ring being respectively juxtaposed about each of said hubs and sealed therewith to prevent leakage between said hub and said ring when a tire is pressurized.

22. A nondestructive tire testing apparatus, comprising:

encoder means for producing an electronic signal indicative of rotation of a tire;

an ultrasonic transmitter for producing ultrasound upon excitation by an electronic signal;

transmitter exciting means responsive to the electronic signal from said encoder means for periodically exciting said ultrasonic transmitter to produce pulses of ultrasound at various locations around a circumference of a tire;

an ultrasonic receiver for receiving ultrasound and producing an electronic signal in response thereto, said ultrasonic receiver being spaced from said ultrasonic transmitter to permit a single wall of a tire to pass there between;

signal processing means for receiving the electrical signal form said ultrasonic receiver, for measuring values of the received electronic signal which characterize the transmission of ultrasound through a wall of a tire during a time interval that continues after the ultrasonic transmitter ceases applying ultrasound to the wall of a tire, and for storing said measured values; and

data processing means for retrieving the measured values stored by said signal processing means, for determining characteristics of the transmission of ultrasound through a wall of a tire from said measured values at a plurality of locations distributed circumferentially about a tire, and for identifying defective locations on a tire form the characteristics of the ultrasound transmitted through a wall of a tire.